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VISUS: a pragmatic expert-based methodology for the seismic safety triage of school facilities

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ABSTRACT Ensuring the safety of people from natural hazards is one of the main concerns of decision-makers in disaster-prone territories, particularly with reference to important public buildings, such as schools. This requires the definition of a rational and effective strategy for risk reduction, based on the preliminary knowledge of the level of risk, critical situations, possible countermeasures, and related costs. Working towards this aim, the SPRINT-Lab researchers of the University of Udine (Italy) developed the VISUS methodology (Visual Inspection for defining Safety Upgrading Strategies). VISUS is a midway approach between data-mining assessments and technical detailed evaluations. Through the pre-codification of the expert-reasoning process, VISUS permits the implementation of a pragmatic technical triage for planning purposes. The outcomes of the assessment process are simple graphical indicators that summarize the evaluations, pointing out the main weaknesses and the needs of intervention for each school. Applications demonstrate that VISUS provides an effective decision-making tool for planning risk mitigation on a regional scale.

Key words: earthquake, school safety, risk mitigation, decision-making, expert reasoning.

1. Introduction

The impact of disasters greatly affects children and youth; this is particularly true if natural hazards strike school facilities, killing or hurting students, teachers, and educational personnel, and affecting the education system. During the 2010 earthquake in Haiti, some 38,000 students and 1,300 teachers and educational personnel died, and almost 4,200 school facilities, including the Ministry of Education building, were destroyed or damaged (UNICEF, 2010). During the 2008 Sichuan earthquake in China, approximately 10,000 students died in their classrooms and more than 7,000 schoolrooms collapsed (Bastidas and Petal, 2012).

The potential magnitude of impacts highlights that, particularly in earthquake-prone areas, the personal safety of individuals in private and, especially, in public school facilities is a legitimate concern for administrators and decision-makers. In fact, they should outline proper strategies for managing and enhancing the safety of individuals; in order to achieve this goal, decision-makers should define specific policies for an effective Disaster Risk Reduction (DRR). In order to settle on proper DRR strategies when dealing with a multitude of buildings at risk, decision-makers should have, first, an overall view of the problem they have to face. Concerning the seismic safety of schools, decision-makers need to have the following information:

- the number of school facilities at risk;
- the potential critical situations associated with each school facility;
- an overall evaluation of safety conditions (i.e., a synthesized judgement) for each school facility;
- the estimated intervention needs and the associated costs;
- the effectiveness of interventions within a comprehensive evaluation of safety.

A specifically designed methodology would facilitate the decision-makers supporting and addressing the definition of effective and rational strategies for risk reduction. This decision-making methodology will provide a global overview of the situation of all of the facilities in the inspected territory. Furthermore, it will facilitate the assessment, for each facility, the risk level, the safety weaknesses, the intervention needs, and the potential costs. With this information, decision-makers will be able to plan which facilities to approach first, also considering the estimates of the required budget allocation and the safety level achieved with the interventions. The planning strategies also depend on how many buildings could be intervened with the available resources (e.g., funds, time, manpower, etc.). Furthermore, the decision-making process should also make allowances for political requirements (e.g., the development of a specific territory, the availability of funds on specific issues, etc.). In practice, it is preferable to provide and support decision-makers with the required elements to properly depict an overall framework, with which they can outline their strategies. Moreover, the methodology should help decision-makers to inform the community about the assessed level of safety, the proven effectiveness of planned interventions, the fairness of their decisions, and, therefore, the motivations behind their choices (Government Office for Science, 2012).

Nowadays, many approaches exist which facilitate the assessment of the seismic safety of buildings in order to plan risk-mitigation strategies at a regional or national scale. These approaches can be grouped according to the assessment procedures and the origin of the input data. Indeed, there are data-mining methodologies based on desk data, which are usually achieved through census or inventories of public buildings [e.g., the Risk-UE methodology by, Mouroux and Le Brun (2006), or the prioritization scheme for seismic mitigation proposed by Grant *et al.* (2007)]. These methodologies usually estimate the seismic structural behaviour through the adoption of fragility curves (e.g., FEMA, 2014) or through estimates obtained with probit equations (e.g., Grimaz, 2009). Another common approach is the Rapid Visual Screening (FEMA 154, 2002), based on a rapid visual check of predefined elements. The sum of the scores associated with each element provides an index expressing the risk level of the building. This procedure is based on the statistical analysis of data sets of specific construction typologies. These approaches quickly provide some information on a large number of buildings; the results, however, are too much coarse to allow the definition of a decision-making support tool for the enhancement of safety in school facilities.

On the other hand, there are sophisticated approaches based on a detailed analysis and investigation of each building, which uses mechanical models and structural simulations for the evaluation of structural vulnerability [for an overview of these methodologies, see Calvi *et al.* (2006)]. These methodologies usually involve long periods of time, high associated costs, and quantitative input data. For these reasons, they are usually used on a small number of buildings. Furthermore, the focus of the mechanical models is the structural seismic response; usually, non-

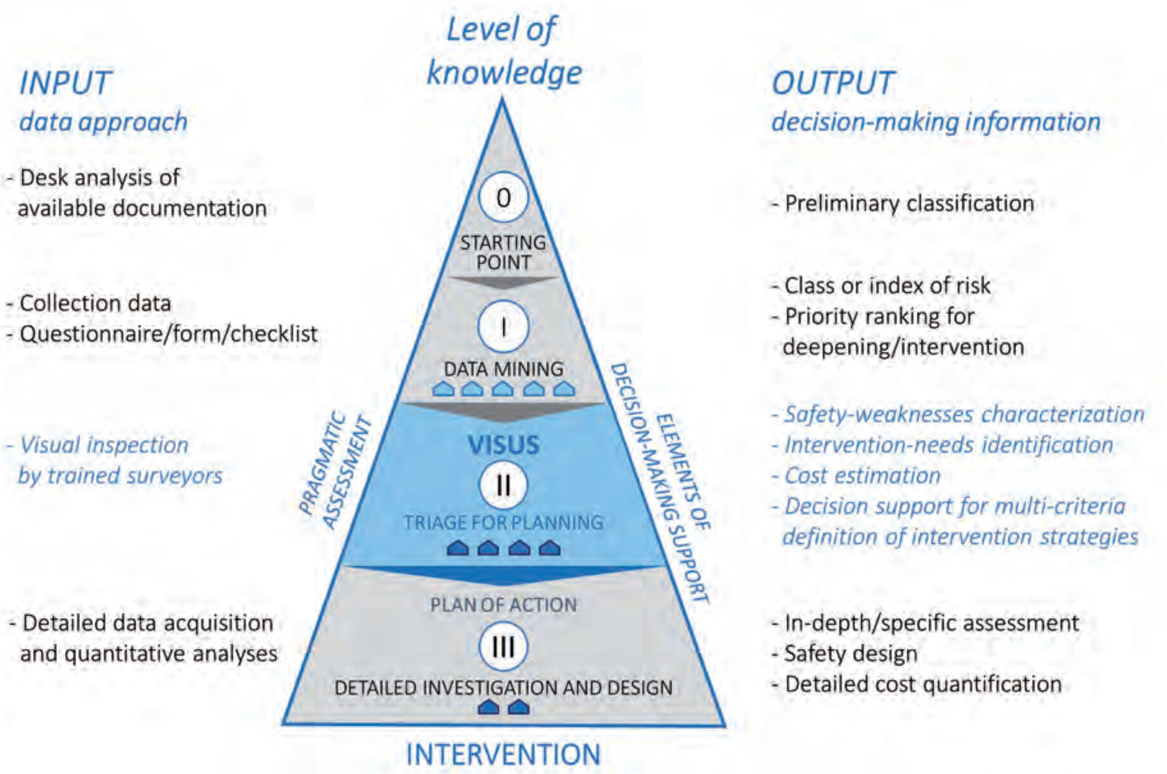


Fig. 1 - Pyramid of the levels of knowledge related to different approaches and methodologies.

structural elements and functional aspects are only indirectly considered, and site conditions, generally, are not deeply investigated.

In order to outline a quick and comprehensive methodology with the specific capability of meeting the requirements of decision-makers, the researchers at SPRINT-Lab at the University of Udine (Italy) developed the VISUS (Visual Inspection for the definition of Safety Upgrading Strategies) methodology. The VISUS methodology operates at an intermediate level of knowledge between data-mining and detailed technical assessments (Fig. 1). The purpose of VISUS is to implement decision-making support tools to define and provide guidelines for risk-mitigation strategies for school facilities into a framework of a comprehensive safety assessment (GADRRRES, 2012) and through a pragmatic procedure based on expert-based technical triage.

2. VISUS methodology

Earthquake protection and disaster medicine feature several similarities in terms of the "nature of the problem to face", especially when it is necessary to manage a problem at a large scale. Starting from this consideration, the SPRINT-Lab researchers developed the VISUS methodology by borrowing the approaches used in medical sectors, and adapting them to technical applications. This idea derived from the observation that, in the medical sector, consolidated methodologies of triage exist for assessing rapidly and pragmatically a large number of patients in order to evaluate their needs as well as to direct them towards necessary interventions or treatments (Iserson and

Moskop, 2007a). The SPRINT-Lab researchers recognized that an analogous situation occurs in the safety assessment of a large number of buildings, particularly in school facilities. Indeed, it is necessary to identify and characterize, through a rapid visual inspection, the specific intervention needs for each school facility, and to support the definition of safety-upgrading strategies and/or priorities at a regional scale.

Although earthquake protection and disaster medicine seem like very different issues, they can be approached by adopting a similar methodology, even if the VISUS methodology deals with safety and technical problems rather than health and medical problems.

Starting from the above-mentioned parallelism, the researchers considered the following points of reference for the design and implementation of VISUS.

a) Technical triage for planning. In the case of DRR of public facilities, it is necessary to establish a plan for intervention, since the actual available resources generally tend to be less than the resources which are needed. When working with a limited amount of resources in terms of money, time, and people, a triage approach has to be applied (Iserson and Moskop, 2007a). A triage approach implies that the resources should be allocated as well as possible, according to predefined values and objectives (Iserson and Moskop, 2007b). A balance should be found between the resources used for the assessment phase, and the resources for the interventions. This implies that the assessment methodology should be “as simple as possible, but not simpler”, in order to limit the time and cost of the assessment phase but provide, at the same time, effective outcomes.

b) Rapid and optimized data collection. The procedure for data acquisition should be as detailed as necessary, in order to provide useful and operative information for the assessment. In order to set up an effective survey procedure, the SPRINT-Lab researchers analysed the expert approach when he/she has to express a comprehensive judgement of a multitude of learning facilities. The knowledge of an expert permits him/her to identify and acquire the substantial information for assessing safety and, with this information, to formulate a judgement. The analyses revealed that a visual (or sensorial) inspection provides most of the information in a limited amount of time. Therefore, the VISUS methodology relies on a rapid and visual data acquisition process (survey) that is modelled after the expert approach. In order to optimize the data collection, the substantial elements that an expert would identify have to be codified into a predefined scheme. This will permit the surveyor to easily recognize the presence or absence of those substantial elements.

c) Effective communication of the outcomes. In order to make the VISUS methodology effective, it is essential to effectively communicate the outcomes. For this reason, by adopting the principles of ergonomics, SPRINT-Lab researchers defined a set of graphical indicators, which permit the simple and immediate communication of the outcomes of the safety assessments. VISUS graphical indicators are suitable for different communication purposes, i.e., to transmit the safety outcomes to decision-makers, and to permit them to communicate those outcomes to the public.

The above points led the researchers to design and develop VISUS as an expert-based assessment methodology. In particular, the Elementary Scenario Reasoning (ESR) technique (Grimaz and Pini, 1999) was adopted, for analysing and pre-codifying the expert reasoning process.

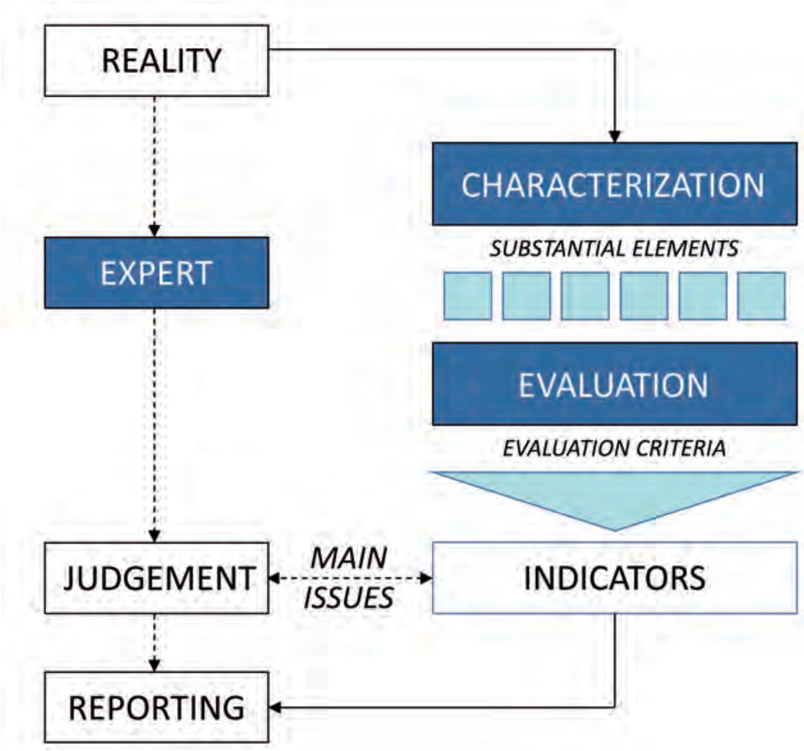


Fig. 2 - Steps of reasoning process of an expert for the judgement formulation and the reporting, as conceived in the ESR technique (Grimaz and Pini, 1999).

2.1. ESR technique

When an expert is called in to provide a safety analysis after a rapid inspection (usually visual), and to develop a brief description of the critical situations and the intervention needs, his/her reasoning process can be associated with the following general questions:

- what substantial information needs to be gathered?
- how should that information be considered in the evaluation?
- how should the judgement be expressed?

The authors assume in this paper, the definition of expert judgement provided by Meyer and Booker (2001), i.e., "an informed opinion based on the expert's training and experience". Therefore, the ability to formulate a judgement moves from the expert's capacity to read and interpret the reality, through the identification and the evaluation of the substantial elements. In the evaluation process, the expert organizes the acquired data according to pre-elaborated conceptual frameworks and heuristics. Then, with the implementation of specific rules and criteria, the expert achieves the final judgement. The ESR technique splits this mental process into two main phases: the characterization and the evaluation phases (Fig. 2). By adopting a procedure for the expert's knowledge elicitation, the technique makes the reasoning process explicit (Fig. 3).

The distinction between the characterization and the evaluation phases provide two separate considerations, namely the ability to characterize the situation and the ability to evaluate it. Therefore, the approach allows the introduction of the role of the surveyor, as one "who is able to acquire the substantial information for the formulation of an expert judgement". Once the expert's reasoning is pre-codified, it is possible to train (non-expert) surveyors so that they can examine the situation and check for the presence of the pre-codified substantial elements (or elementary scenarios). Subsequently, the rules and criteria defined for the evaluation phase are applied to the

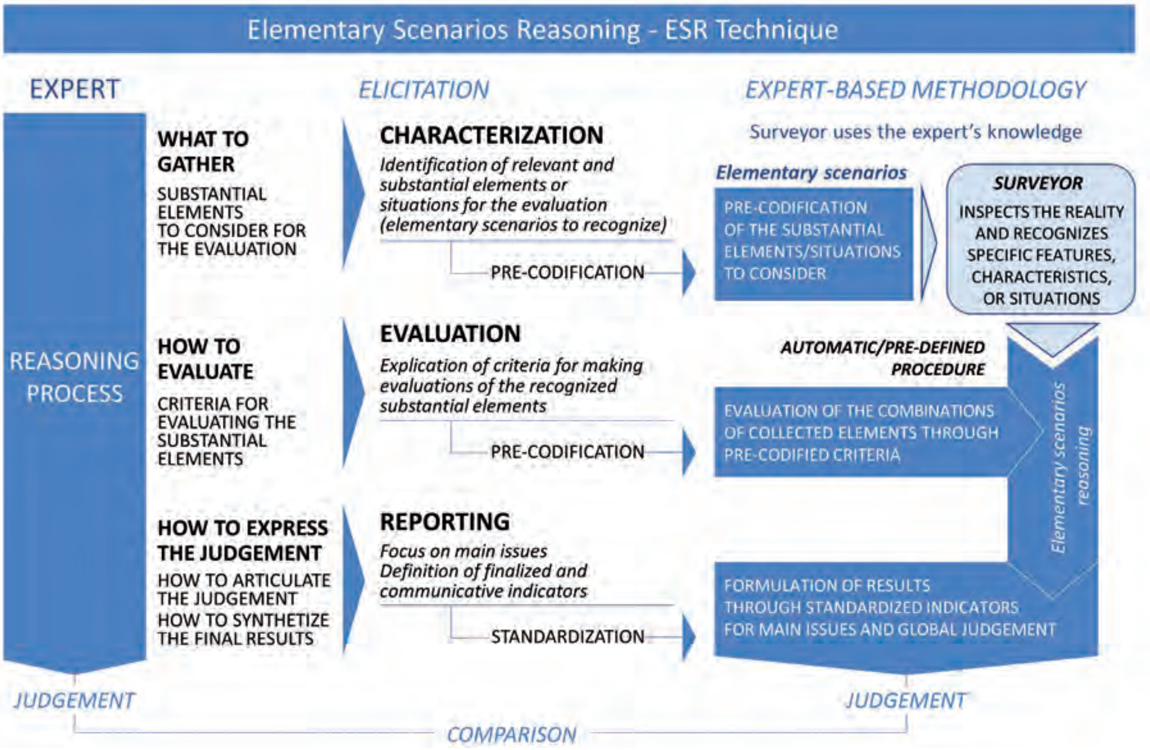


Fig. 3 - ESR technique. Elicitation of expert's knowledge for defining expert-based methodologies.

collected data (manually or automatically), the final judgements are achieved, and the outcomes can be represented through the graphical indicators and reports. In this framework, the predefinition of the graphical indicators standardizes the outcomes and facilitates the communication of results, providing both specific information and global overview.

The elementary scenarios could be represented in different ways, i.e., through the description of the features (Grimaz and Pini, 1999), the definition of index classes (Grimaz *et al.*, 1995), or the use of pictograms (adopted for the application of the VISUS methodology and described below).

The evaluation phase can be based by different types of rules and criteria: numerical algorithms (Grimaz and Pini, 1999), logic trees (Grimaz and Malisan, 2013), fuzzy sets (Grimaz *et al.*, 2011), matrices (Grimaz *et al.*, 1995), simplified calculations (Gattesco *et al.*, 2011), etc.

In order to implement a "pragmatic" methodology for the assessment, the Pareto principle (or 80/20 rule) has been adopted. The 80/20 rule states that 20% of the known variables will account for 80% of the results (Basile, 1996). For this reason, experts should expend particular effort to identify the most relevant elements describing the universe of the pre-codified elementary scenarios and discard the secondary data (Fig. 4); the purpose is to acquire only the essential data for achieving a sufficiently reliable judgement.

2.2. VISUS: an expert-based methodology

The SPRINT-Lab researchers applied the ESR technique to define the VISUS methodology. The first application of VISUS was in the field of seismic engineering. The goal of VISUS

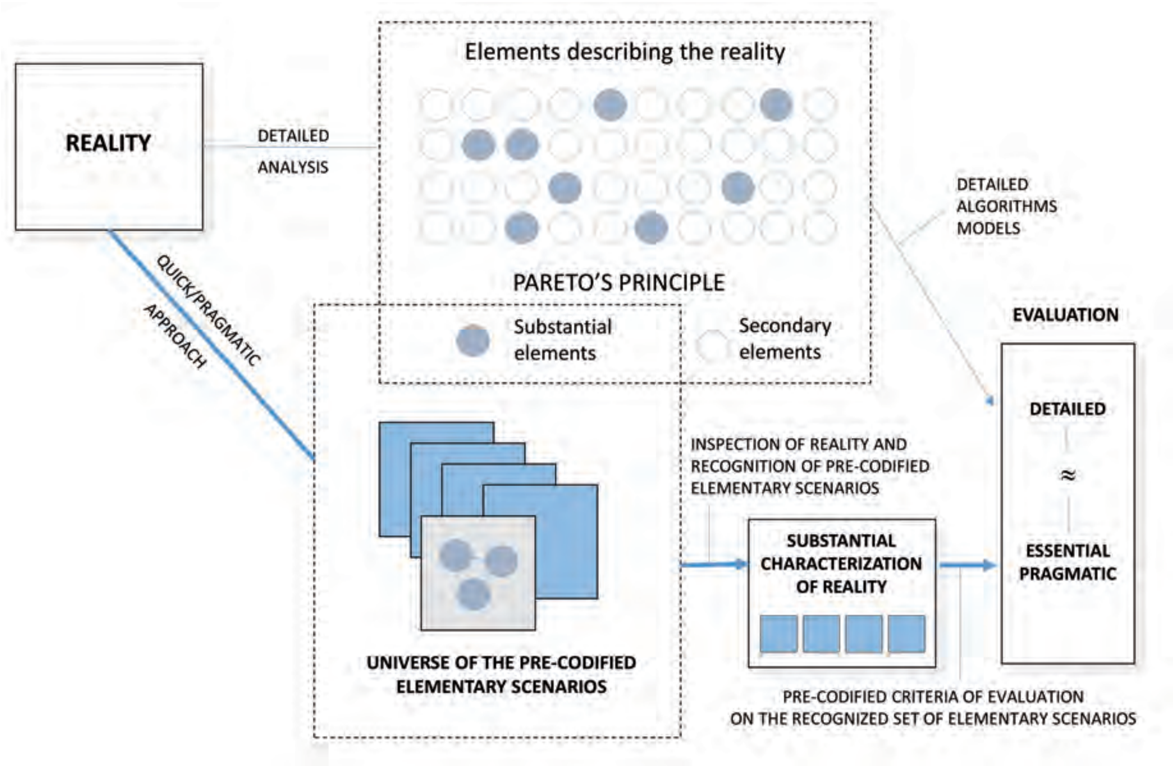


Fig. 4 - Framework of the characterization phase for triage assessment.

implementation was "to define a quick and pragmatic tool as a support for decision-makers in the definition of safety upgrading strategies of existing schools". Furthermore, the concept of "seismic safety" was defined as the condition in which, as consequence of an earthquake, no injuries or deaths occur (Fig. 5). Considering the seismic hazard, the judgements on safety were made according to five main issues (Fig. 5), which are: site, global structure, local structure, non-structural elements, and functional aspects (a short description of each of them is provided below). The application of the expert's knowledge elicitation process permitted the implementation of VISUS as an expert-based methodology, referring to the life safety performance, and focusing on the five main safety issues.

During the development of the VISUS methodology and its adaptation to a specific risk assessment, the SPRINT-Lab researchers identified and pre-codified the substantial elements that could help to characterize each safety issue. At the same time, they also defined the rules and criteria to apply to the substantial elements in order to reach final judgments.

In the following, the strategies and criteria adopted for the implementation of the main phases of VISUS (characterization, evaluation) and the use of graphical indicators for final reporting purposes are described.

2.3. The characterization phase

The characterization phase is based on the capacity of a VISUS surveyor to recognize, in the reality he/she is observing, the elementary scenarios pre-codified by experts. Therefore, the characterization phase strongly relies on the pre-codification of the elementary scenarios. These

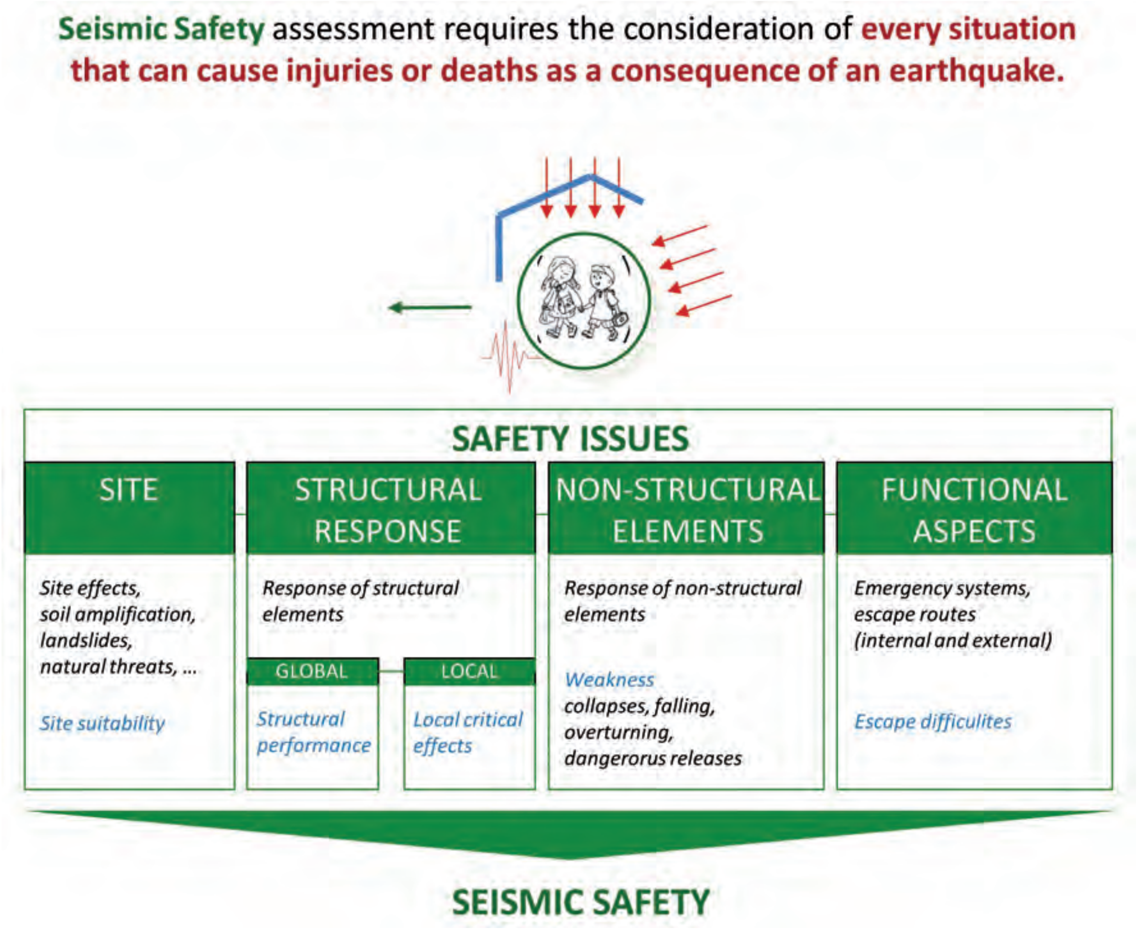
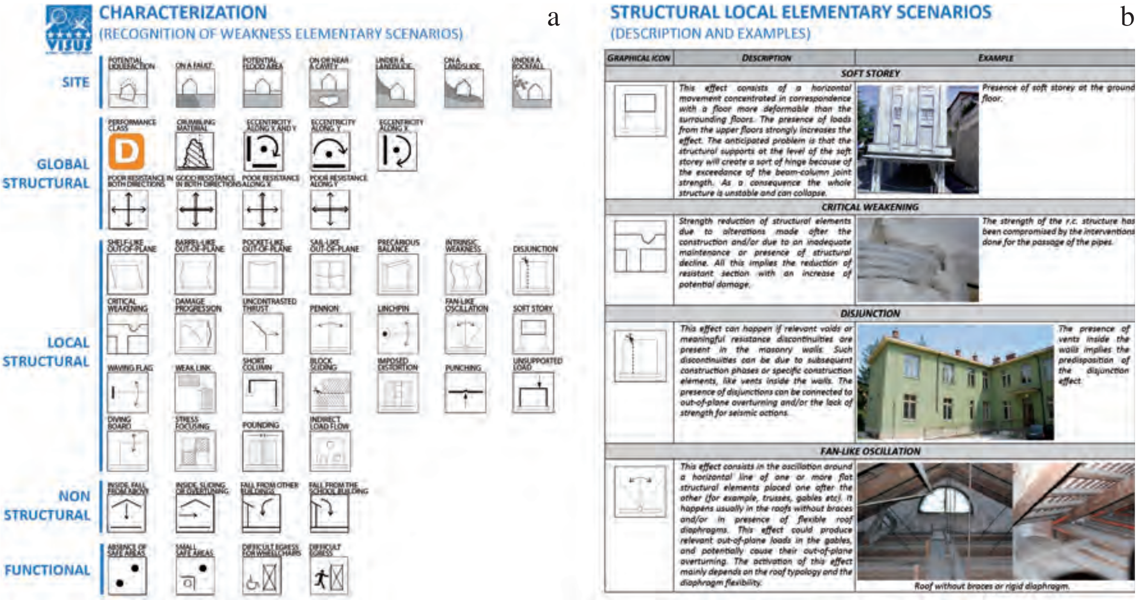


Fig. 5 - The seismic safety issues considered in the VISUS methodology.

will permit the acquisition of the substantial elements of the reality, discarding the trivial elements, and therefore accelerating both the survey and the evaluation phases. The identification and pre-codification of the elementary scenarios are carried out through a brainstorming of experts (both VISUS and specific-risk experts) and applying an elicitation process based on the ESR technique. Although this process requires high-level expertise and a specific approach to the problem, it simplifies the characterization phase considerably. Indeed, the characterization is based on the visual identification/recognition of the elementary scenarios previously defined and therefore it allows that the surveyor may have shallow knowledge of the methodology and of the approach.

The assessment of safety requires the consideration of all of the elements that could potentially cause injury or death, and therefore requires the adoption of a holistic approach. In the case of seismic safety assessment, the VISUS methodology considers the five main issues previously mentioned: site, global structure, local structure, non-structural elements, and functional aspects. Fig. 6a shows the pictograms identifying the different elementary scenarios for each main issue. The critical site issues can be represented by unstable conditions, such as impending rock falls or landslides, faults in the near field, cavities in the ground, potential liquefaction, inundated areas, etc. The presence of one of these conditions implies the need to evaluate the possibility of, for example, retrofitting the building or moving it to another, more stable site. The global structural



GRAPHICAL ICON	DESCRIPTION	EXAMPLE
	SOFT STOREY	
	This effect consists of a horizontal movement concentrated in correspondence with a floor more deformable than the surrounding floors. The presence of loads from the upper floors strongly increases the effect. The anticipated problem is that the structural supports at the level of the soft storey will create a sort of hinge because of the exceedance of the beam-column joint strength. As a consequence the whole structure is unstable and can collapse.	Presence of soft storey at the ground floor.
	CRITICAL WEAKENING	
	Strength reduction of structural elements due to alterations made after the construction and/or due to an inadequate maintenance or presence of structural decline. All this implies the reduction of resistant section with an increase of potential damage.	The strength of the r.c. structure has been compromised by the interventions done for the passage of the pipes.
	DISJUNCTION	
	This effect can happen if relevant voids or meaningful resistance discontinuities are present in the masonry walls. Such discontinuities can be due to subsequent construction phases or specific construction elements, like vents inside the walls. The presence of disjunctions can be connected to out-of-plane overturning and/or the lack of strength for seismic actions.	The presence of vents inside the walls implies the predisposition of the disjunction effect.
	FAN-LIKE OSCILLATION	
	This effect consists in the oscillation around a horizontal line of one or more flat structural elements placed one after the other (for example, trusses, gables etc). It happens usually in the roofs without braces and/or in presence of flexible roof diaphragms. This effect could produce relevant out-of-plane loads in the gables, and potentially cause their out-of-plane overturning. The activation of this effect mainly depends on the roof typology and the diaphragm flexibility.	Roof without braces or rigid diaphragm.

Fig. 6 - VISUS characterization. Icons identifying the pre-codified elementary scenarios (a). Example of instructions for recognizing the elementary scenario in same cases related to the structural local issue (b).

outcomes can be synthesized through elementary scenarios indicating the global robustness of the structure (assessed through simplified calculation methods, fragility curves, or expert judgement). In addition, the recognized scenarios allow the identification of additional structural global problems, such as the presence of crumbling structural material, torsion along one or both principal directions, non-uniformity of robustness along the principal directions, or inadequate structural lateral-load-resistant elements. The local structural scenarios focus instead on the behaviour of some parts of the structure, such as walls, roof, slabs, etc.; the list of local structural scenarios could change slightly country by country, depending on construction typologies. Fig. 6b shows some examples of local structural elementary scenarios, with a short description and photos in support of the recognition process. Non-structural characteristics include the potential problems connected with the presence of non-structural elements that can fall, causing injury or death (e.g., false ceilings, bookcases, chimneys, etc.). In this case, the elementary scenarios point out the potential problems inside and outside the building, including if any element could fall, slide, or overturn on people. Finally, functional aspects are evaluated, such as the assessment of the egress system and of the meeting points, since even the possibility to easily leave the building and reach a safe place is a primary aspect of the seismic safety evaluation.

The elementary scenarios could refer either to a typology (i.e., typological elementary scenario) or to a behaviour (i.e., behavioural elementary scenario). A surveyor can identify a typological elementary scenario through the observation of the building and the comparison (a sort of pattern recognition) with the graphical scenarios. The behavioural elementary scenarios, instead, are based on the recognition of a (generally structural) behaviour: this can imply that the surveyor has to recognize different features characterizing the specific behaviour (for example, the presence of braces, the rigidity of a diaphragm, etc.). The identification of a typological scenario is usually very simple for the surveyor, and little training is required. On the other hand, the recognition

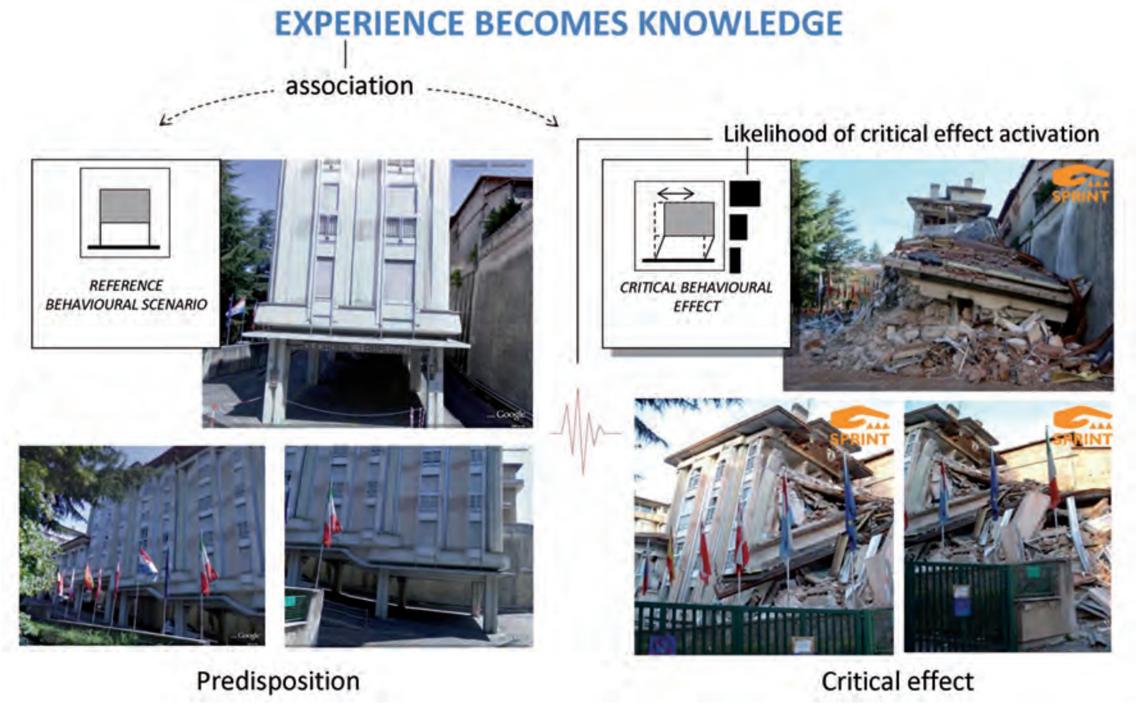


Fig. 7 - The expert uses his experience to define a judgement: a) the expert is able to recognize specific features/ characteristics associated with a specific potential critical effect (predisposition); b) the expert associates the predisposition with a potential critical behavioural effect and the likelihood of the critical effect activation.

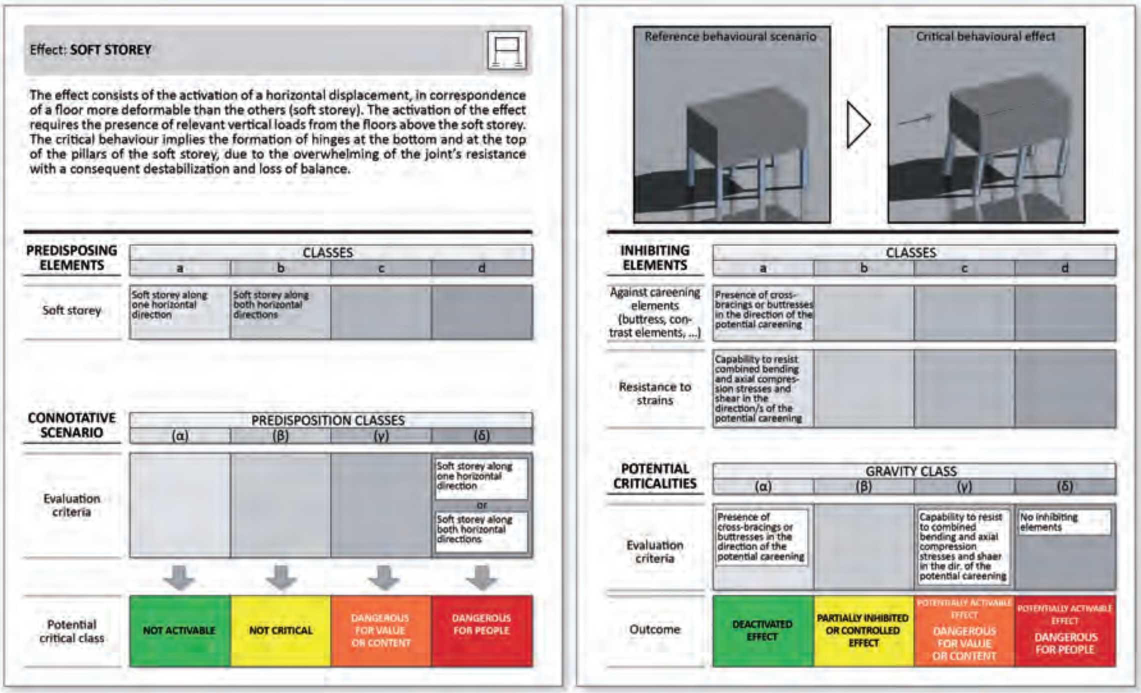
of a behavioural scenario requires a trained surveyor, but this both reduces the "work" of the surveyor (in terms of number of features to recognize) and simplifies the evaluation process, since simple evaluation will have already been done by the surveyor. Moreover, the ability to identify behavioural scenarios should be learned by the surveyors, and this implies that they should be adequately trained. For this reason, VISUS can also be seen as a capacity-building and knowledge-transfer tool.

During the surveys, specific forms (and/or tablet-based apps) support the surveyor for the data collection. The forms permit the rapid collection of the data and show to the surveyor the substantial elements he/she has to recognize during the survey. The survey procedure also requests pictures to support the observations.

2.4. The evaluation phase

Once the VISUS surveyor has completed the characterization phase, the data are available for the evaluation. The evaluation phase can be developed either manually (experts apply the pre-codified rules and criteria) or in an automatic way, through the definition of algorithms based on the predefined rules and criteria. Therefore, judgements are rapidly and automatically expressed for each main issue, and the results are provided according to the VISUS predefined indicators.

The identification of the rules and criteria for the evaluation requires a collaboration of ESR and technical experts, in order to elicit the technical expert's approach for the definition of the judgement. During the development of VISUS for the assessment of seismic risk in school facilities, the SPRINT-Lab researchers were at the same time ESR and seismic risk experts. The



Effect: **SOFT STOREY**

The effect consists of the activation of a horizontal displacement, in correspondence of a floor more deformable than the others (soft storey). The activation of the effect requires the presence of relevant vertical loads from the floors above the soft storey. The critical behaviour implies the formation of hinges at the bottom and at the top of the pillars of the soft storey, due to the overwhelming of the joint's resistance with a consequent destabilization and loss of balance.

PREDISPOSING ELEMENTS	CLASSES			
	a	b	c	d
Soft storey	Soft storey along one horizontal direction	Soft storey along both horizontal directions		

CONNOTATIVE SCENARIO	PREDISPOSITION CLASSES			
	(α)	(β)	(γ)	(δ)
Evaluation criteria				Soft storey along one horizontal direction or Soft storey along both horizontal directions
Potential critical class	NOT ACTIVABLE	NOT CRITICAL	DANGEROUS FOR VALUE OR CONTENT	DANGEROUS FOR PEOPLE

INHIBITING ELEMENTS	CLASSES			
	a	b	c	d
Against careening elements (buttress, contrast elements, ...)	Presence of cross-bracings or buttresses in the direction of the potential careening			
Resistance to strains	Capability to resist combined bending and axial compression stresses and shear in the direction/s of the potential careening			

POTENTIAL CRITICALITIES	GRAVITY CLASS			
	(α)	(β)	(γ)	(δ)
Evaluation criteria	Presence of cross-bracings or buttresses in the direction of the potential careening		Capability to resist to combined bending and axial compression stresses and shaer in the dir. of the potential careening	No inhibiting elements
Outcome	DEACTIVATED EFFECT	PARTIALLY INHIBITED OR CONTROLLED EFFECT	POTENTIALLY ACTIVABLE EFFECT DANGEROUS FOR VALUE OR CONTENT	POTENTIALLY ACTIVABLE EFFECT DANGEROUS FOR PEOPLE

Fig. 8 - Example of VISUS form for the evaluation of the local structural effects. The example concerns the "soft storey" effect.

adopted criteria were based on the experience derived from the direct observation of seismic damage, comparing the pre-event situation ("reference behavioural scenario") with the associated "critical behavioural effect" (Fig. 7). This approach splits the evaluation process, considering two aspects separately: a) the predisposition of specific configurations to produce predefined critical behavioural effects in case of an event (Fig. 7a) and, b) the likelihood of the critical effect activation as a consequence of a specific ground motion magnitude (Fig. 7b).

Fig. 8 shows the example of the pre-codified process for the evaluation of a specific local structural effect. In particular, the example illustrates the criteria defined for the "soft storey" effect. The form presents a brief description of the effect, and a sketch that illustrates the "reference behavioural scenario" and the "critical behavioural effect". The form is divided in two parts: first, tables and criteria allow the assessment of the "potential critical class" associated with the effect, then other tables and criteria allow the evaluation of the "gravity class" which could be associated with the effect. A specific table shows and characterizes the pre-identified "predisposing elements", which are considered relevant to the effect. Through the implementation of specific criteria (defined by experts), it is possible to assign the "potential critical class" to the effect. The "potential critical class" could be:

- "not activable" (i.e., not capable of being activated);
- "not critical";
- "dangerous for value or content";
- "dangerous for people".

If the evaluation of the "potential critical class" is "not activable" or "not critical", the procedure stops, since there are no concerns on that specific effect. Otherwise, it is necessary to proceed with the estimation of the influence of the "inhibiting elements" (described in a specific table). By

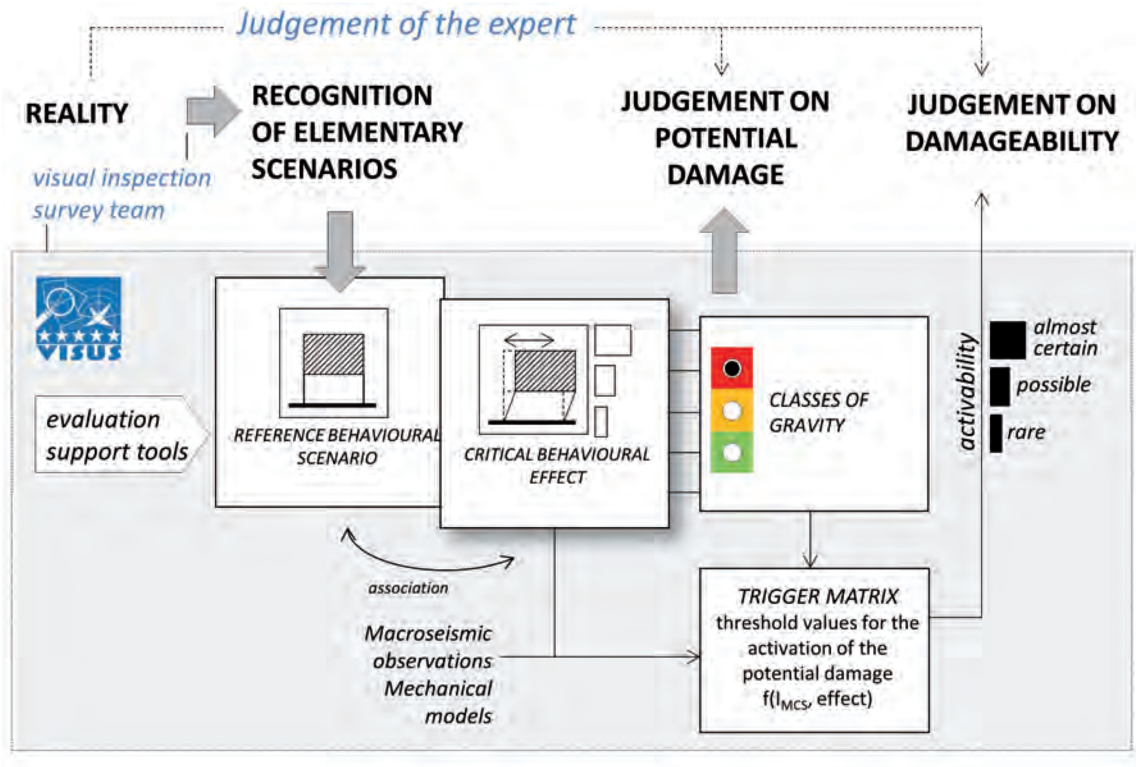


Fig. 9 - Sketch of the evaluation procedure: from the recognition of elementary scenarios (characterization) to the evaluation of predisposition and activation.

considering the effect of the “inhibiting elements”, the evaluation criteria associate an outcome with the potentially critical effect in terms of gravity class. The potential outcomes are:

- “deactivated effect”;
- “partially inhibited or controlled effect”;
- “potentially activable effect - dangerous for value or content”;
- “potentially activable effect - dangerous for people”.

Fig. 9 shows a sketch of the evaluation procedure with reference to the “soft storey” effect: the analysis of the characterized substantial elements identifies the “reference behavioural scenario”, which is predisposed to a specific critical effect. Every critical effect was studied and the experts defined the magnitude of the hazard that could activate (trigger) the critical effect. Grimaz and Maiolo (2010) and Grimaz and Malisan (2014) illustrated some examples of seismic damage to industrial facilities and lifelines, and buildings prone to near field effects, respectively. The observations were used to define and improve the definition of the trigger values in the trigger matrix (Fig. 10). The trigger matrix associates the likelihood of activation to each behavioural scenario (and to the related critical effect) considering different levels of magnitude of the action. In the seismic case, and for VISUS evaluations, the reference parameter describing the magnitude of the hazard is the macroseismic intensity. Local relationships allow the association of the macroseismic intensity with the peak ground motion values [*PGA*, *PGV*: Gómez Capera *et al.* (2007)] which are usually defined in national seismic hazard maps. VISUS methodology considers three levels of likelihood for the activation of the critical scenario with the defined

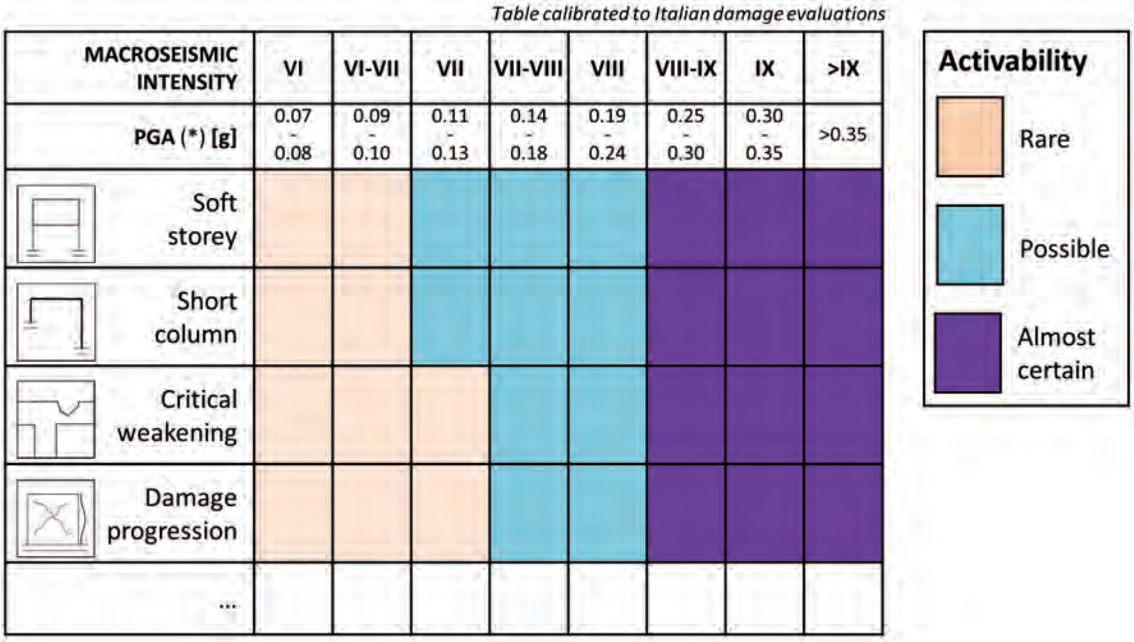


Table calibrated to Italian damage evaluations

MACROSEISMIC INTENSITY	VI	VI-VII	VII	VII-VIII	VIII	VIII-IX	IX	>IX
PGA (*) [g]	0.07 - 0.08	0.09 - 0.10	0.11 - 0.13	0.14 - 0.18	0.19 - 0.24	0.25 - 0.30	0.30 - 0.35	>0.35
Soft storey	🟧	🟧	🟦	🟦	🟦	🟪	🟪	🟪
Short column	🟧	🟧	🟦	🟦	🟦	🟪	🟪	🟪
Critical weakening	🟧	🟧	🟧	🟦	🟦	🟪	🟪	🟪
Damage progression	🟧	🟧	🟧	🟦	🟦	🟪	🟪	🟪
...								

Activability	
🟧	Rare
🟦	Possible
🟪	Almost certain

(*) the ranges of PGA associated to Macroseismic Intensities are defined adopting the equations proposed in Gómez Capera *et al.* (2007).

Fig. 10 - Extract of the trigger matrix for defining the activability condition of same critical effects (local structural effects).

action level (Figs. 9 and 10): rare, possible, and almost certain. A graphical indicator illustrates the anticipated potential activation (activability) of each recognized effect (Fig. 9).

Each "critical behavioural effect" is evaluated according to the potential effects on people's safety, in the case the effect is activated. The evaluations are expressed through three gravity or Warning Levels (WL), describing the potential consequences on personal safety:

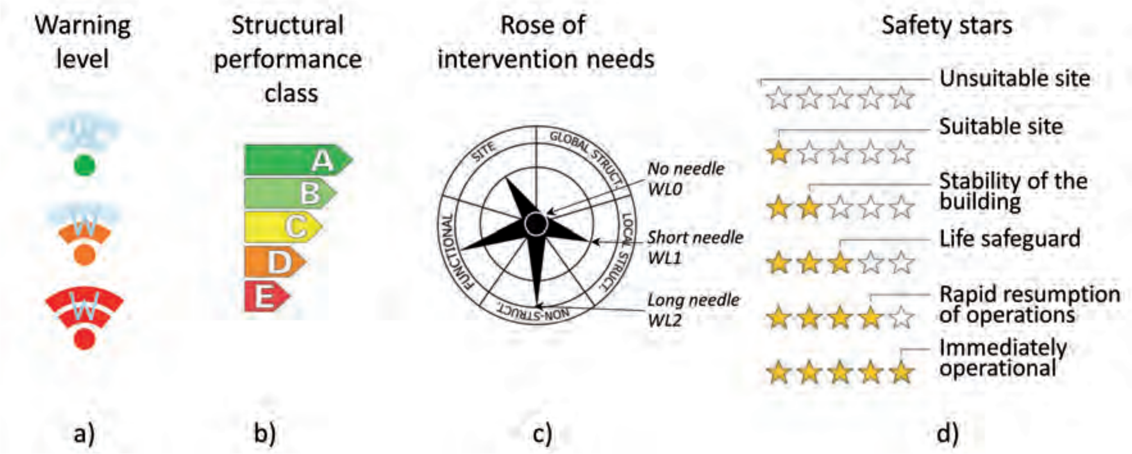


Fig. 11 - VISUS graphical indicators: indicators for the warning levels (a) or structural performance class (b), rose of intervention needs (c), and safety stars (d).

- WL0: absence of concerns for personal safety;
- WL1: potentially difficult situations for personal safety;
- WL2: potentially heavy consequences for personal safety.

2.5. VISUS graphical indicators

The evaluation process assigns a final judgement to each main safety issue. Here arises the delicate problem of using appropriate language to efficiently communicate the results of the evaluation to the end-users (mainly public administrators and decision-makers, often without a technical background). In order to allow a synthesized visualization of the outcomes, the VISUS methodology adopts the main principles of ergonomics to provide a set of graphical indicators (Fig. 11). The VISUS graphical indicators are:

- Warning level (Fig. 11a): the indicator expresses the warning level in terms of potential negative consequences for personal safety (WL0, WL1, WL2), using the visual analogy of the acoustic level of a siren alarm;
- Structural performance class (Fig. 11b): this indicator synthesizes the evaluation of the structural performance of a building (Grimaz *et al*., 2011). If only poor data are available, the performance class is expressed through the warning level indicator. Instead, if quantitative detailed data are available, a specific performance class indicator is adopted, recalling the energy-label classification. Analogous with the method adopted for indicating the energy-efficiency classes of houses, the performance class label assigns a structural performance class to each building;
- Rose of intervention needs (Fig. 11c): the rose of intervention needs summarizes in a single graphical indicator the main critical situations of the building assessed, according to the evaluation of the five safety issues (site, global structural, local structural, non-structural, and functional weaknesses). The symbol synthesizes the judgements on the five safety issues by associating a warning needle to each. The length of each needle identifies the level of warning (WL0: no needle; WL1: short needle; WL2: long needle). Therefore, one or more needles indicate the presence of safety warnings in the building, while a rose without needles means that the building has achieved the safety goal, and no intervention is required;
- Seismic safety stars (Fig. 11d): all of the evaluations are synthesized in the assignment of the safety stars. The concept behind the seismic safety stars is similar to that adopted in other fields where a comprehensive judgement is required (e.g., quality of hotels, quality of cars, etc.). At the end of the assessment, each star is assigned when specific requirements are satisfied. The stars are assigned progressively, according to the following criteria:
    - No star assigned: unsuitable site (presence of WL2 for site);
    - 1st star assigned: the site is suitable (there is no WL2 for site). This means that there are no severe natural or man-made threats affecting the site in which the school is located;
    - 2nd star assigned: stability of the building (there is no WL2 for structural global evaluation of structures). This means that the global collapse of the building is very unlikely considering the seismic action defined in the seismic codes;
    - 3rd star assigned: life safeguard (absence of WL2 in any safety issue). There are no critical situations that could imply heavy consequences on personal safety (this implies no collapses or critical falls of non-structural elements);

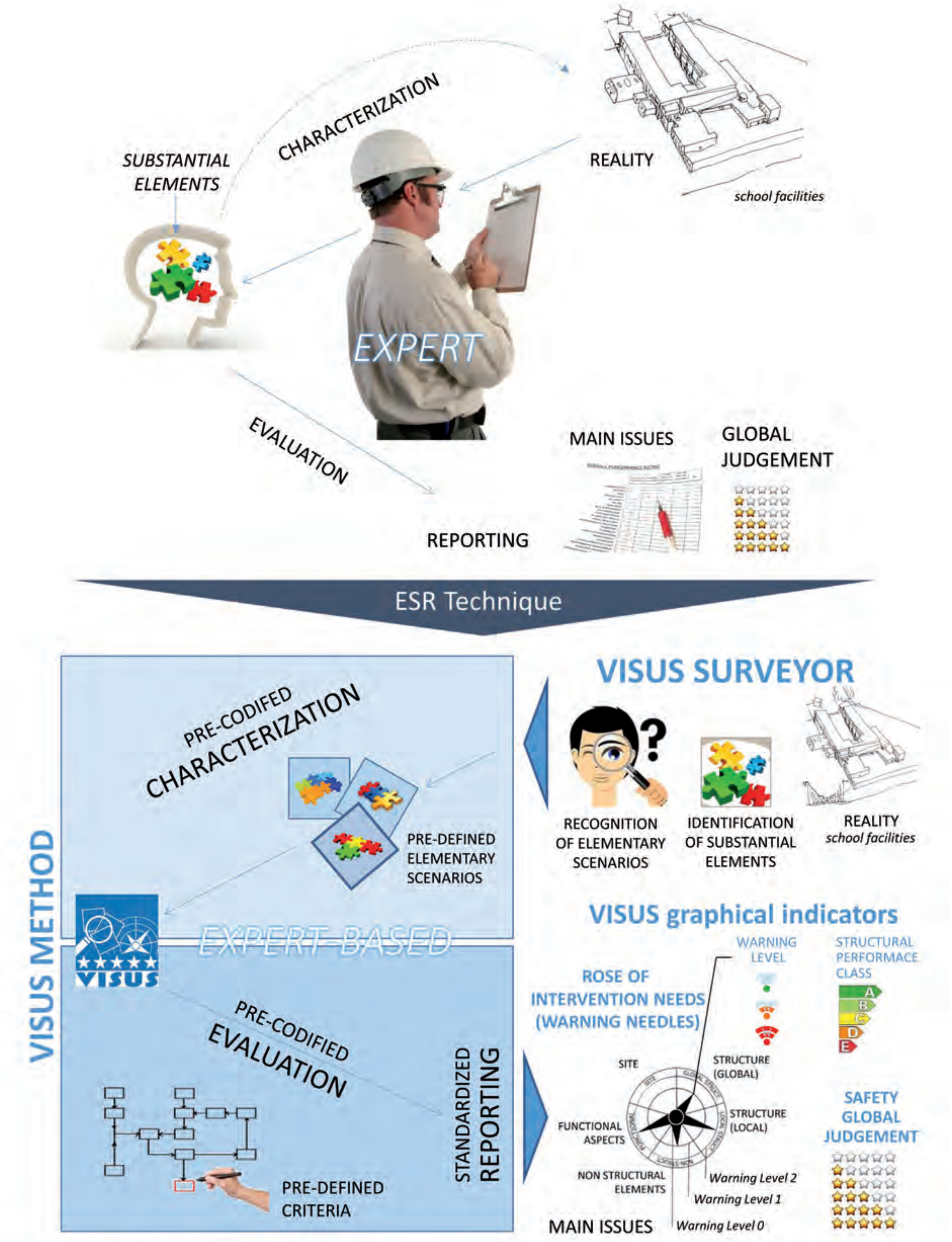
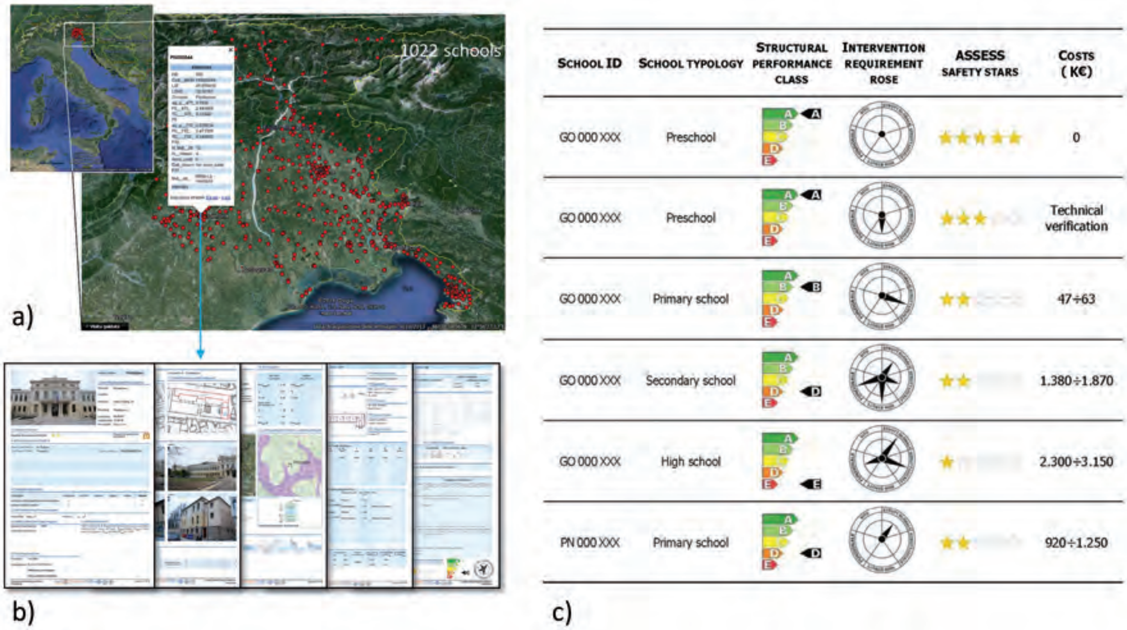


Fig. 12 - Schematic representation of the VISUS methodology. VISUS permits the passage from the expert assessment to an expert-based surveyor investigation, and the pre-codified evaluation and standardized reporting.



School ID	School typology	Structural performance class	Intervention requirement rose	ASSESS safety stars	Costs (K€)
GO 000 XXX	Preschool	A		★★★★★	0
GO 000 XXX	Preschool	A		★★★	Technical verification
GO 000 XXX	Primary school	B		★★	47÷63
GO 000 XXX	Secondary school	D		★★	1.380÷1.870
GO 000 XXX	High school	E		★	2.300÷3.150
PN 000 XXX	Primary school	D		★★	920÷1.250

Fig. 13 - Outcomes of the VISUS methodology after the application on the 1022 schools in Friuli Venezia Giulia (north-eastern Italy): a) the schools were geo-referenced and included in a GIS, together with the outcomes of VISUS; b) a report was developed for each school; c) the outcomes were synthesized through the VISUS indicators in a collective report (VISUS panel).

- 4th star assigned: rapid resumption of operations (absence of WL1 for structural global and local). There are only criticalities that could imply difficult situations for personal safety; this implies no diffuse damage;
- 5th star assigned: immediately operational (absence of WL1 for all issues). After the event, it is possible to immediately reuse the school without interventions.

The set of VISUS graphical indicators proved very useful for the definition of a pragmatic decision-making support tool. In fact, VISUS graphical indicators express the seismic safety of each school facility, distinguishing the evaluation results for each main safety issue; furthermore, they address the necessary interventions for each school. Therefore, the decision-making tool based on the VISUS graphical indicators facilitates the definition of a list of priorities for risk-reduction actions, according to different political and administrative criteria. At the same time, the graphical indicators help maintain a clear vision of the overall scenario. In fact, the performance class shows the structural resistance compared to current standards; the rose of intervention needs, taking into account all the factors contributing to the risk definition, represents a sort of report of the situation; and the seismic safety stars globally define the “safety performance” by referring to the main indicators of seismic safety.

Fig. 12 depicts the VISUS methodology as the result of the passage, using the ESR technique, from the expert assessment to an expert-based surveyor investigation. The figure also synthesizes the entire VISUS methodology, highlighting the phases of characterization and evaluation.

All the VISUS indicators are grouped into the VISUS panel (Fig. 13c), which is one of the tools supporting the decision-making process. The VISUS panel defines the priorities of interventions on the basis of criteria defined by public administrators. The costs for the safety upgrade of each

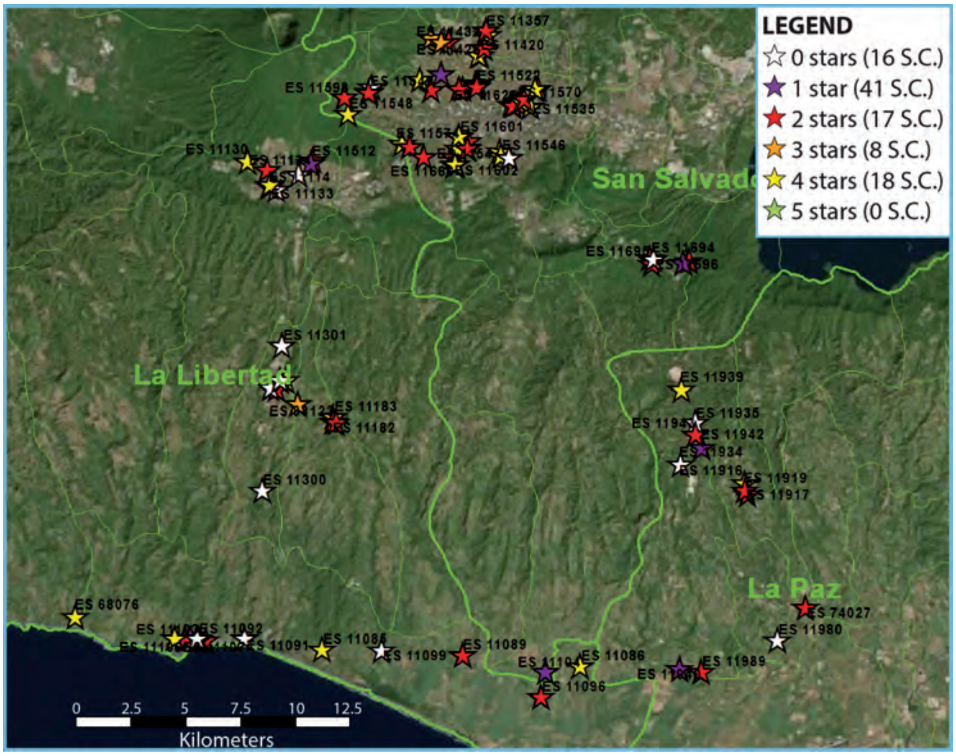


Fig. 14 - Application in El Salvador. The stars pinpoint each assessed school complex (S.C.). The colour of the marker indicates the number of achieved VISUS safety stars.

school were computed by taking into account the outcomes of the rose of intervention needs and increases associated with specific recognized conditions (e.g., constraints associated with cultural heritage buildings, difficulties associated with site construction, location).

3. Examples of application of the VISUS methodology

The VISUS methodology was first adopted during the ASSESS project (Grimaz *et al.*, 2016) to study the seismic risk of school facilities as well as to define useful tools to reduce such risks. The ASSESS project facilitated the application and validation of the VISUS methodology in more than 1,000 schools in the Friuli Venezia Giulia region (north-eastern Italy) (Fig. 12a). It also enabled the comparison of the results of deep investigation with the results of a visual approach (VISUS methodology). The favourable comparison of VISUS proved the efficacy of the methodology as triage. The ASSESS project promoted the input of experts on VISUS methodology, and technical experts on seismic hazard, structural seismic behaviour, non-structural elements, and functional aspects. The methodology was tested during many surveys performed directly by experts in the field of seismic engineering, and these surveys allowed some novice VISUS surveyors to be trained. At the end of the project, a report was developed for each school (Fig. 12b), illustrating the outcomes. The VISUS panel further synthesized the outcomes in a collective report for all the schools (Fig. 12c).

Subsequently, UNESCO adopted the VISUS methodology and applied it to the assessment of school facilities during a pilot project in El Salvador. After a short (24 hours) course, 15 university students (5th year - faculty of civil engineering at the University of El Salvador) were trained, and the utilization of VISUS increased their knowledge in the field. In ten days, the students analysed 100 schools (Fig. 14), with a total number of 494 structural units in the departments of La Libertad (costal area), La Paz (rural area, mountain area), and San Salvador (urban area).

UNESCO submitted the VISUS methodology (in terms of both procedure and results) to an international committee of experts during the seventh session of the International Platform for Reducing Earthquake Disaster (IPRED) on May 2014, in Kazakhstan. The reason for this was to obtain an authoritative evaluation of the applicability of VISUS as a technical triage and capacity-building tool within the Comprehensive School Safety framework (GADRRRES, 2012). As a result, a UNESCO resolution recommended that governments implement efforts necessary to improving the safety of educational facilities, including among others, the development of assessment by a rapid triage method such as VISUS (UNESCO Resolution May 30, 2014, Almaty, Kazakhstan).

4. General remarks on VISUS methodology

The application of the VISUS methodology in different contexts has given rise to the following considerations, organized according to specific key points.

- *Role of the expert:* VISUS relies fundamentally on the knowledge of the involved experts. The elicitation process is the most delicate phase. VISUS requires experts in the technical subject that will be analysed (for example, civil engineering) and experts in the ESR technique, who consult the technical experts and investigate the expert's mental processes, which are often "unconscious". This is particularly important for the adaptation of the methodology to the peculiarities of the country where VISUS will be applied (in terms of typologies, construction characteristics, quality of materials, etc.).

- *Technical triage as a tool for decision-making:* the principal outcome of VISUS is a decision-making tool designed for administrators and decision-makers to simplify and settle the basis of their decisions. The decision-making support tool is designed to provide simple answers to the main concerns of public administrators for DRR, thus identifying the global situation, the safety weaknesses, the intervention requirements, and the relative costs. The VISUS assessment plays the role of technical triage and, when required, suggests to the decision-makers to proceed to a deeper assessment with a more detailed investigation.

- *Outcomes for intervention planning:* the VISUS methodology aims at implementing a decision-making support tool in the definition of risk-mitigation strategies. The outcomes of the VISUS methodology, presented with graphical visual indicators, permit the use of VISUS for planning effective intervention strategies for risk reduction, with a multi-criteria approach.

- *Uniformity of judgements:* the separation of the two phases of characterization and evaluation, and the definition of the pre-codified elementary scenarios and criteria and rules for evaluation, result in standardized evaluations and judgements on safety issues, even if different surveyors did the characterization.

- *Communication:* the outcomes, presented as graphical indicators, were revealed to be effective tools for the communication. The data can be entered into a Geographical Information

System (GIS) application and represented on maps, according to multi-criteria queries.

- *Knowledge transfer and capacity building:* the VISUS methodology permits the transfer of knowledge from an expert to a non-expert (who is a trained surveyor). The application of VISUS during the ASSESS project revealed that the VISUS methodology is very easy to learn, while the trial during the pilot project in El Salvador proved that VISUS is a good tool for capacity-building purposes.
- *Adaptability and extendibility:* VISUS is a methodology based on a framework that allows the tailoring of specific tools to decision-making in different fields and for different aims. The methodology can be adapted to different local features and to different hazard/threats. The ESR technique can be extended to specialists of different hazards, in order to obtain a comprehensive multi-hazard assessment.

5. Conclusions

VISUS is a methodology developed as an expert-based procedure for the assessment of the safety of public buildings, and more specifically of school facilities. Specific application of the methodology demonstrated that VISUS constitutes a valid decision-making support tool for public administrators and decision-makers in defining effective strategies for safety upgrading.

The experience highlighted that VISUS graphical indicators simplify the communication of the results of safety assessments. Furthermore, the methodology is adaptable and customizable to the specific needs, competencies, and hazards of different countries around the world.

Even if VISUS was originally developed to assess the seismic safety of schools, it can be easily extended to different hazardous scenarios, such as floods, hurricanes, fire, and even for evaluating ordinary maintenance conditions. This extension appears necessary if a comprehensive safety assessment is required. In fact, considering safety as a condition in which no one gets hurt or dies, it is necessary to analyse each situation that could cause difficulties, harm, or even death. Therefore, it is necessary to consider every hazard or threat that could plausibly affect the school and the users. Currently, the authors are working to extend the VISUS methodology to fulfil this ambitious aim.

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